# Strategy for plant taxonomic research in South Africa 2015–2020

J.E. Victor, G.F. Smith & A.E. van Wyk

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The South African National Biodiversity Institute (SANBI) was established on 1 September 2004 through the signing into force of the National Environmental Management: Biodiversity Act (NEMBA) No. 10 of 2004 by President Thabo Mbeki. The Act expands the mandate of the former National Botanical Institute to include responsibilities relating to the full diversity of South Africa's fauna and flora, and builds on the internationally respected programmes in conservation, research, education and visitor services developed by the National Botanical Institute and its predecessors over the past century.

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SANBI's mission is to champion the exploration, conservation, sustainable use, appreciation and enjoyment of South Africa's exceptionally rich biodiversity for all South Africans.

SANBI Biodiversity Series publishes occasional reports on projects, technologies, workshops, symposia and other activities initiated by or executed in partnership with SANBI.

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# Table of Contents

Introduction ..... 1

Purpose of the Strategy ..... 3

Development of the Strategy ..... 5

Human capacity for plant taxonomic research in South Africa ..... 9

Material available for taxonomic research ..... 17

Strategic objectives ..... 19

Programmes of activity for taxonomic research ..... 21

Programme of activity to improve the herbarium collections as a research resource ..... 29

Discussion and conclusions ..... 33

Acknowledgements ..... 35

References ..... 37

# Introduction

The *Strategy for plant taxonomic research in South Africa 2015–2020* (hereinafter referred to as the Strategy) forms part of the *Biosystematics research strategy for South Africa* (Victor et al. 2013). Taxonomic research underpins biodiversity studies and involves discovering, naming, describing and classifying biological organisms. In this document, the term taxonomy is used in a broad sense and therefore includes systematics, which is the organisation and classification including investigation of the causes and processes of evolution and the study of phylogeny (Stuessy et al. 2014).

The widely distributed seaweed, *Ecklonia maxima*, was the first South African 'plant' to be figured in a publication. A rather stylistic rendition of the species appeared in 1598 in the account of Cornelis de Houtman of an expedition (1595–1597) that rounded the Cape en route to the East Indies. Subsequently numerous plant taxonomic studies have provided many new insights into the phylogenetic relationships of plants and their classification. Today this particular seaweed is classified in a kingdom of life (Chromalveolata) only distantly related to the one that includes the green land plants (Plantae), the latter being the focus of the Strategy presented here. Photographer: Gideon F. Smith.

The mandate of the South African National Biodiversity Institute (SANBI), which comes from the National Environmental Management: Biodiversity Act No. 10 of 2004: Section 11, includes responsibilities to:

- Coordinate and promote the taxonomy of South Africa's biodiversity.
- Collect, generate, process, coordinate and disseminate information about biodiversity.
- Undertake and promote research on indigenous biodiversity.

This document partly fulfils SANBI's mandate by providing a coordinated framework for plant taxonomic research that will be implemented within SANBI and promoted among other institutions and funding agencies. By coordinating and promoting plant taxonomic research throughout South Africa, this Strategy provides leadership in this regard.

The Flora of Southern Africa (FSA) region (South Africa, Namibia, Botswana, Lesotho and Swaziland) has the richest temperate flora in the world with approximately 22 000 species described to date, harbouring about 10% of the world's vascular plant flora in conjunction with extremely high levels of endemism, and three of Conservation International's global biodiversity Hotspots (Mittermeier et al. 2004). The bulk of this diversity (> 20 000 species) is found within South Africa, an estimated 57% of which is strictly confined (endemic) to the country (Germishuizen et al. 2006; Steenkamp & Smith 2006).

# Purpose of the Strategy

Taxonomic research has historically been driven by curiosity in the rich and diverse flora that develops through the normal course of exploration and curatorial work, and by personal motivation to investigate groups of interest, in which problems are uncovered and investigated. The disadvantage of this approach is that the real value of the results can be underestimated or remain unrecognised, and sometimes urgent problems remain unresolved. Taxonomic research would benefit from having a coordinated strategy to address the needs of end users in a strategic manner, to improve the relevance and impact of research products that are delivered.

As a government institution, SANBI is funded predominantly by the taxpayers of South Africa, thus its policies and strategies should ultimately stand in the service of society. The development of a strategy to promote and channel plant taxonomic research extends much more widely than the institution itself. It needs to be acknowledged that a considerable amount of biodiversity research on the South African biota is conducted outside SANBI, notably at institutions such as universities and museums, as well as by amateur/private taxonomists and naturalists. Tertiary institutions such as universities are also responsible for the training of the human capital eventually employed by SANBI. On the other hand, SANBI, with its regional network of herbaria, botanical gardens and most comprehensive plant collections for southern Africa globally, is an indispensable resource to be consulted by anybody studying the botanical diversity of the region.

Hence this Strategy will be circulated and available to taxonomic researchers at universities, as well as be made accessible on the internet to be consulted by all potential stakeholders. In so doing it is also deliberately aimed at stimulating the involvement by people from outside SANBI, and to encourage them to focus on the same priorities. In addition, a list of taxonomic expertise and projects has been made available online at (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies), with the intention of facilitating the coordination of taxonomic research in South Africa. The Strategy will also be circulated to funding agencies so that funding towards the identified priority research programmes can be stimulated. SANBI also encourages taxonomic researchers from outside the organisation to make use of its extensive herbarium and living plant collections, as well as excellent library resources.

The benefits of a strategy for plant taxonomic research are that it provides guidelines for research priorities; communicates the value of taxonomic research to the public, academic institutions and funding agencies; makes the most strategic use of limited time and resources; guides future decisions on capacity development, staff recruitment and training; stimulates the dissemination of priority taxonomic information to end users; and provides a shared vision to guide research.

**The vision of the Strategy is to document and provide predictive classifications for South African plant species, enabling users to identify and access knowledge about them, so that all can understand, conserve and benefit from biodiversity.**

This document addresses primarily the plant taxonomic research in South Africa, but includes discussions on herbarium collections and associated data, capacity for conducting research, and implementation of the Strategy. These topics are addressed in more detail in Victor (2015). During the development of this Strategy, the authors consulted taxonomists from most universities of South Africa, as well as abroad (Royal Botanic Gardens Kew, Missouri Botanical Garden, and University of Zurich), to share, and where appropriate, incorporate views beneficial to Strategy development and implementation in South Africa.

# Development of the Strategy

Botanical exploration of South Africa started early in the 17th century (Gunn & Codd 1981). Based on extensive collections of Cape plants, the *Flora capensis* was established in 1860 by Harvey and Sonder, and the final volume was published in 1933. Active taxonomic research, including the production of Floras, has continued since then. Despite an extensive body of literature on the South African flora, gaps still exist. The first step for prioritising taxonomic research was therefore to evaluate what has been done and what is most urgently required.

Until 2013, the National Herbarium, Pretoria (PRE) Computerised Information System (PRECIS) documented the primary collection data of most plant specimens housed in the three SANBI herbaria (National Herbarium, Compton Herbarium and KwaZulu-Natal Herbarium), with collection information for more than 1.2 million plant specimens. This database was interrogated using 'indicators' (Victor et al. 2015) to reveal problematic plant groups and thus possible gaps in taxonomic knowledge. These gaps were used to inform where the priority research activities should be aimed until 2020, taking into consideration the current trends in taxonomic research within South Africa and internationally. The Strategy will be reassessed every five years.

## *Needs analysis*

An extensive list of end users of taxonomic research products and the type of information they could require was compiled by Morin et al. (1988). A notable omission from this list is botanical researchers, comprising all disciplines that require plant material for their research.

Current end users of SANBI herbaria were investigated to add to identifying the end users of taxonomic research and their needs. Virtually all herbaria throughout South Africa are resources for the public requiring identification of plants, and many herbaria offer such a service for a broad spectrum of users. Analysis of the records of specimens submitted for identification to the three SANBI herbaria shows that the most frequent users of this service are (in no particular order):

- University researchers and students.
- Other, non-SANBI herbaria.
- Environmental consultants.
- Members of the public.
- The Agricultural Research Council (especially veterinary institutes) of the Department of Agriculture of the South African government.

- The Council for Scientific and Industrial Research of the Department of Science and Technology of the South African government.
- Natural history museums (national and international).
- Local interest groups e.g. the Botanical Society of South Africa.
- Commercial plant nurseries and garden centres.
- Conservation agencies e.g. South African National Parks, South African provincial nature conservation bodies.
- Non-herbarium SANBI staff e.g. Millennium Seed Bank project, Invasive Aliens Early Detection and Rapid Response Programme, Threatened Species Programme, and horticulturalists.

Requests for data addressed to SANBI herbaria include information such as species lists for geographical areas, and distributions of species. In order of frequency these clients are: taxonomists from SANBI herbaria, researchers at universities, scientists from other SANBI divisions, environmental decision makers (e.g. consultants), environmental policy makers, conservationists, veterinarians, and agronomists (P. Winter, pers. comm.). These end users all require accurate taxonomic information and data derived from herbarium specimens and their associated labels to enable correct recommendations on, for example, proposed land use, and informed decisions that take occurrence of threatened taxa into account.

Identification of stakeholder needs was necessary to establish important directions for research activities. Accurate and reliable scientific information about plant and animal species is becoming increasingly important in South Africa as economic development puts pressure on sustainable use of natural resources. The basis for that information is taxonomy (West 1996). Standard information provided by taxonomists includes names, descriptions, distribution and habitat information, and evolutionary relationships; but additional information such as unique properties, ecology, pollination syndrome and conservation information is often gathered.

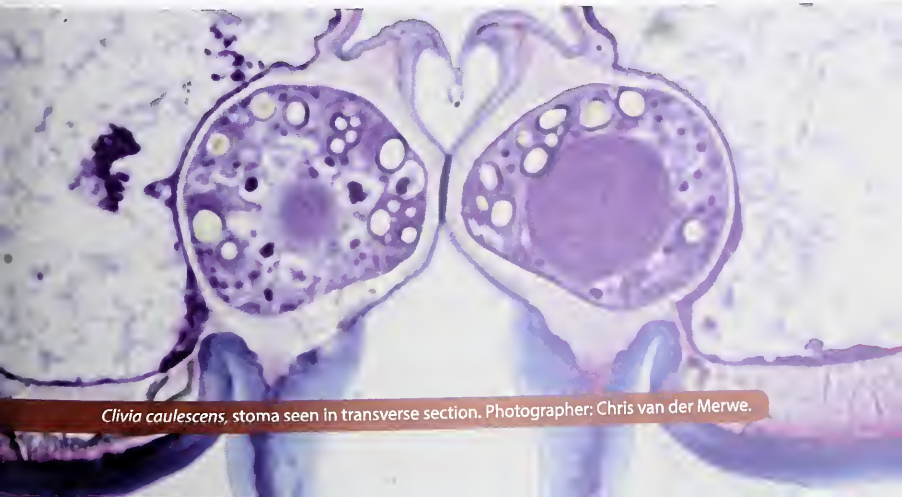
In 2002, a national workshop for stakeholders and end users of botanical information and herbaria was held at the National Herbarium of SANBI (Steenkamp & Smith 2002). One of the objectives of the workshop was to determine the kind of botanical information needed by user groups, along with setting priorities associated with providing this information. The workshop was attended by 34 stakeholders and end users from agricultural institutions, botanical societies, conservation agencies, environmental consultants, ethnobotanists, universities and others. The five most important requirements determined as a result of this workshop, in descending order of priority, were:

- Updated, accurate checklists for all South African plant species.
- Species lists for specified geographical areas enriched with additional information such as Red List status or residential status (e.g. aliens).

- A centralised information database system with all associated information on the plants that is factually accurate and freely accessible to all.
- Fully representative herbarium collections.
- An efficient and affordable plant identification system.

A review of enquiries, data requests, visitors and services requested from SANBI's herbaria from 2010 to 2014 shows that there is still continuous pressure on herbarium staff for these activities to be prioritised, and the results of the workshop conducted in 2002 remain current. These requirements largely depend on accurate specimen identifications, which in turn rely on precise species demarcations and comprehensive information that are generated through taxonomic research. Taxonomic researchers are well placed to provide this information to enable the work in virtually all other fields of biological endeavour, such as to assist conservationists to assess the extinction risk of the species, and to determine how to manage them.

South Africa's exceptionally rich and diverse flora faces challenges in terms of management and conservation. Careful planning, sufficient human capacity and resources, and efficient use of capacity and resources are required to ensure that the demands of these tasks are appropriately and comprehensively met. The capacity as at December 2014 for conducting taxonomic research in South Africa was assessed to determine whether there are sufficient resources in terms of: (1) human capacity, (2) research material, and (3) financial and other resources, to implement and monitor a strategy for plant taxonomic research in South Africa in the future. This enabled identification of shortages of capacity or resources that might prove to be an obstacle in implementing the Strategy.



*Clivia caulescens*, stoma seen in transverse section. Photographer: Chris van der Merwe.

# Human capacity for plant taxonomic research in South Africa

There are approximately 35 professional plant taxonomists employed in academic posts as lecturers and/or researchers in South Africa, 19 of which are at SANBI and 16 at universities. In addition to taxonomic researchers, there are many trained taxonomists employed as herbarium curators or technical support staff, both at SANBI and at universities; at least five of these staff members conduct research as well. At least nine people who are not employed as plant taxonomists, conduct plant taxonomic research; in addition at least 13 retired professionals actively contributed to taxonomic research in the past five years.

Few plant taxonomists employed in South Africa will retire from formal employment within the next five years, and more than half of the plant taxonomists in the workforce are under the age of 50. The main obstacle to maintaining or increasing capacity at SANBI and other government-funded institutions such as universities and museums, is the Employment Equity Act, number 55 of 1998 which discourages recruitment of researchers from the white population group. In the past five years, six plant taxonomist scientist posts have been advertised at SANBI's three herbaria, and it was possible to fill only two of these with candidates meeting the Employment Equity targets.

## *Current state of taxonomic research*

The main sources of information for plants are family treatises, geographical Floras and taxonomic revisions of genera. For species-level information, various internet web pages provide information on species, particularly if they are of horticultural or economic value. At genus level research is usually published in the form of revisions of genera. A compilation of all taxonomic revisions for South African plant genera for this study reveals that there are 50 genera that were last revised prior to 1900, and of these, 16 genera (mostly of the Aizoaceae/Mesembryanthemaceae) have never been revised. Family-scale treatments have often been done by production of a conspectus or Flora-style fascicle. The Flora of Southern Africa (FSA) project was initiated in 1955 aiming to produce family treatises for the 180 angiosperm families (recognised at the time) in South Africa, Botswana, Lesotho, Swaziland and Namibia. Progress with the FSA project was not as rapid as expected, and after 40 years only about 18% of the taxa had been treated. A decision to de-emphasise the FSA in favour of publishing manuscripts in SANBI's in-house journal, *Bothalia*, under the banner of 'FSA contributions' was taken in 1995. Although the FSA project does not currently exist as a formal project, volumes may still be published in future in *Strelitzia*, an in-house journal of SANBI. Additional major sources of taxonomic information for southern Africa have

Some members of the Aizoaceae (Mesembryanthemaceae), the most taxonomically problematic plant family in South Africa.

Checklist and regional Floras of South Africa published by SANBI.

been published in *Strelitzia*. A series of regional Floras have been published or are still in progress, with the eventual aim of providing coverage of the whole country. Floras for the northern provinces (comprising Gauteng, Limpopo, Mpumalanga and North West and covering over 5 700 species), Western Cape and parts of the Northern and Eastern Cape ('Core Cape Flora' covering approximately 9 200 species and 'Extra Cape Flora' covering about 3 700 species) have recently been completed (Retief & Herman 1997; Manning & Goldblatt 2013; Snijman 2013); and those for Free State (almost 3 000 species) and Eastern Cape (over 7 300 species) have been completed and submitted for publication. A volume on the remaining parts of the Northern Cape is in preparation, covering an estimated 3 200 species, and will be submitted for publication in 2016. Once the Flora of KwaZulu-Natal is completed, these regional treatises will cover the flora of the entire country.

## *Trends in plant taxonomic research*

According to Von Staden et al. (2013) there has been a decline in revisionary output by taxonomists. An assessment was conducted to determine whether this corresponds with lowered productivity of taxonomists, using number of new taxa of South African plants described per year as an indicator (Victor 2015). Results showed that the number of new taxa described over the past 34 years by South African and international botanists fluctuates overall, but has not declined; however, the number of new taxa described as part of a revision has declined with a corresponding increase in number published in stand-alone papers or as part of a revision of a small group of species (Victor 2015). From these data we can infer that the number of revisions being published has declined, which is supported by the survey by Von Staden et al. (2013).

Light microscopes are still the most essential tool for taxonomists conducting alpha-taxonomic research. Photographer: Pieter Bester.

The decline in revisionary output corresponds with an increase in the number of species described in stand-alone publications as well as an increase in numbers of papers in molecular phylogeny being published. Fragmentation of publications into units describing new taxa or revising small sections of a genus enables the information to be available for use in checklists and by end users much faster than working for years to consolidate everything and publish it when the revision is complete. An electronic means of dissemination, such as a single-portal online Flora, would solve the problem of fragmentation and enable all published literature to be available in a consolidated source immediately.

Research programmes should not place too much emphasis on the production of Floras, as revising plant genera or sections thereof may be a more effective and more rapid way of solving taxonomic problems and identifying potential new species. Flora-style contributions of plant families are useful for consolidating what is known, but may not be an immediate priority. As is often the case globally, consolidation of information into Flora-style products can be done concurrently or after the primary research is conducted and published.

Although the conclusions reached by Von Staden et al. (2013) – that taxonomic output in terms of 'revisions' has declined – is supported, this cannot be extrapolated to taxonomic research output as a whole, but rather to changes in emphasis of research topics. An analysis of the output by taxonomic researchers in terms of numbers of papers published in peer-reviewed journals (Victor 2015) shows that there is potential capacity to conduct and publish taxonomic research, although much of the research output effort is not spent on taxonomic research.

The needs of most end users are for information of a micro-taxonomic nature, but molecular phylogenetic work supplies information of a macro-taxonomic nature. Using modern analytical techniques to create phylogenies is useful, and indeed often necessary, to resolve difficult taxonomic groupings, such as clarifying delimitation of genera. In the past, certain authors claimed that advances in molecular biology and phylogenetic reconstruction were driving research to the detriment of traditional taxonomy (Wortley et al. 2002). It is therefore important not to overemphasise phylogenetic studies at the expense of alpha-taxonomy, but rather support comprehensive taxonomic revisions making use of datasets from a diverse range of sources (including molecular) where necessary. It should, however, be noted that classifications produced by the phylogenetic school of classification are, in contrast to those of the evolutionary school, often less informative to end users of plant names (e.g. Van Wyk 2007; Brummitt 2014).

There appears to be a split between taxonomists doing molecular phylogenetic work (mainly at universities) and those doing more traditional alpha-taxonomy (mainly at SANBI), and perhaps not enough collaboration exists to unite those two ends of the spectrum. Fostering collaboration to ensure that phylogenetic work is not the end

product, but rather incorporated into revisions, would be of great benefit to taxonomic research products, because although end users do not directly require the results of macro-taxonomic studies, it is still a vital component of research.

Peer-reviewed publications remain an important yardstick for measuring productivity of taxonomists. However, some of the most important products to end users often include those that are published in other forms. Among the more important local products is the checklist of South African plants, which has been published in hard copy (Germishuizen et al. 2006) and is available online under the title 'Plants of southern Africa' or POSA on the SANBI website (http://posa.sanbi.org/searchspp.php). In addition, certain products generated predominantly by SANBI taxonomists, some with valuable contributions from university-based taxonomists, have been very popular, e.g. *Seedplants of southern Africa: families and genera* (Leistner 2000); *Herbarium essentials* (Victor et al. 2004); and *Guide to the plant families of southern Africa* (Koekemoer et al. 2015). University taxonomists produce books to a lesser extent, but notable are publications such as *Medicinal plants of South Africa* (Van Wyk et al. 2009), *Field guide to trees of southern Africa* (Van Wyk & Van Wyk 2013), *Field guide to the wild flowers of the Highveld* (Van Wyk & Malan 1997) and *Orchids of South Africa – a field guide* (Johnson & Bytebier 2015).

A discussion forum was held by SANBI staff members (D. Raimondo in collaboration with L. von Staden, M. Hamer and J.E. Victor) at the Southern African Society for Systematic Biology conference in Arniston, July 2012, to determine ways to stimulate the production of taxonomic revisions. The participants were, inter alia, asked what obstacles prevented them from carrying out taxonomic revisions, and reasons given were: low impact factor of taxonomic journals, time consuming nature of revisionary work leading to lower publication output, and a lack of information about research priorities. It was suggested that Department of Science and Technology funding should be directed towards projects that would contribute towards specific priority research targets.

## Recommendations for addressing capacity shortages

A review of capacity for plant taxonomic research in South Africa (Victor 2015) concludes that there is a severe shortage of capacity available to manage the country's diverse flora in terms of taxonomy and provision of foundational information. Taxonomists in South Africa are productive and are not limited by financial and infrastructural resources. However, there are still vast areas of the country that remain undercollected, and many taxa underrepresented in herbarium collections, which indicate that taxonomists are partially limited by lack of plant material for research purposes and from which specimen data records can be databased for end users. Intense study of a smaller group of taxa can generate a large amount of information, as opposed to often, but not always, less intensive studies such as a Flora contribution. With approximately 20 000 plant species in South Africa and around 40 researching taxonomists (including technicians appointed in non-academic

posts), the ratio of number of species to taxonomist is about 500 species to one. The large number of taxa (about 3 800) represented by fewer than five specimens in SANBI herbaria illustrates how little is known for a large portion of the South African flora. It can therefore be concluded that more human capacity for taxonomic research in South Africa is urgently required. For now, to maximise the effectiveness of existing human capacity, prioritised activities need to be identified and efforts redirected towards these (Victor et al. 2015).

A future potential problem is addressing employment equity targets. There is an unequal distribution of taxonomic researchers at universities, with fewer traditionally black universities offering post-graduate training in taxonomy. The lack of capacity for postgraduate students to study taxonomy at the traditionally black universities is a severe impediment to successful transformation of the workforce in South Africa. More universities could undertake postgraduate training of students in taxonomy with external assistance in the form of a taxonomist co-supervisor from SANBI or another university. SANBI has at least 12 senior plant taxonomic researchers who have the ability to co-supervise research projects, but only four are currently involved in this activity. Bursaries offered to students at universities that currently do not have capacity to supervise postgraduate studies in taxonomy could stimulate the interest in plant taxonomy amongst previously disadvantaged population groups. A solution to this would be for SANBI to more actively promote collaboration with these universities to offer skills for co-supervising or mentoring postgraduate students, and facilitate (or offer) bursaries for this purpose, especially targeting universities currently without taxonomists. However, with only about 40 positions for plant taxonomic researchers in the country, there is limited opportunity for employment and therefore the number of bursaries offered should be calculated carefully to ensure a steady supply for the availability of posts. To provide a choice of quality taxonomists the pool of candidates needs to be competitive, therefore it is essential to train more taxonomists than posts becoming available. The specialist nature of taxonomy limits career opportunities, therefore taxonomists need to have skills in other fields so that they can find careers in for example environmental consulting or conservation, two fields in which trained taxonomists have successfully found employment in South Africa.

An alternative solution to providing future capacity for taxonomic research is for scientists to mentor interested and talented support staff employed in technical positions in herbaria; provided such candidates have an interest in, and aptitude for, taxonomic research. At least 11 senior SANBI plant taxonomists are actively mentoring junior scientists, graduates conducting internships or technicians, or have done so in the past five years.

Traditionally black universities urgently need to create taxonomy posts so that equity can be redressed. This is one of the long-term solutions to the problem. In the meantime it would be beneficial for SANBI to produce more textbook-type resources (for example Victor et al. 2004; Koekemoer et al. 2015), where the need exists, so that universities that do not employ taxonomists can still offer the course in a suitably stimulating manner to captivate potentially interested taxonomists.

The need for more taxonomists can clearly be justified, but may not be prioritised in a country that already has such shortages of capacity in pre-primary, primary, secondary and tertiary education and social services, such as an effective police force, for example. Therefore aside from lobbying for more jobs to be created, there is an urgent need to utilise existing resources (human and other) effectively, and develop a strategy to ensure that priority activities are conducted.

# Material available for taxonomic research

## *Herbarium specimen collections*

Herbaria are indispensable resources for taxonomic research. South Africa has at least 72 herbaria, housing more than 3.2 million plant specimens. The collection of plant specimens and associated data in herbaria underpins plant taxonomic and broader scientific work. Although there are a large number of specimens in herbaria around South Africa, the representation of specimens geographically is unequally distributed. In the three SANBI herbaria, there are parts of the interior of the country that are represented by fewer than 10 specimens per quarter degree grid square (representing roughly 25 × 25 km, or 625 $km^2$), and vast areas represented by fewer than 50 specimens per quarter degree grid square. For more than 10 quarter degree grid squares, SANBI herbaria do not have any specimens at all. In many cases this can be attributed partly to lower levels of diversity but even if this is the case, the number of specimens should be higher than 50 per quarter degree grid to be representative of the flora for the area.

Herbarium specimens. Photographer: Janine Victor.

Another indicator of representation of South African flora in herbaria is the number of specimens per species. Species with very low numbers of specimens in herbaria are characteristically rare taxa and often distributed in inaccessible or hard to access localities. It is important to establish a dedicated and comprehensive programme to collect specimens that are representative of all taxa. Ideally, the full geographical distribution range and morphological variation of taxa should be represented in collections. This improves the knowledge base of plant diversity and is a prerequisite for conducting taxonomic research of a high standard, and ultimately, providing comprehensive information to end users.

## *Databased information*

The database of plant specimen information is a critically important product provided by SANBI, with information disseminated online. PRECIS was developed in the 1970s, with non-expert typists transcribing information from herbarium specimen labels into the database. PRECIS subsequently became the largest botanical database in South Africa and the southern hemisphere, progressively capturing and documenting the information from over 1.2 million preserved plant specimen labels. The information in this database was transferred to a Botanical Research And Herbarium Management System (BRAHMS) database in 2013. In spite of quality control procedures that are in place at the three SANBI herbaria, errors in the database abound, exposing SANBI to severe criticism. All herbaria need to have quality control procedures in place to ensure that the information provided is of sufficient standard to be used by end users.

# Strategic objectives

SANBI is committed to contributing to the targets set by the Global Strategy for Plant Conservation (GSPC), including Target 1, which aims to complete an electronic World Flora Online (see http://www.plants2020.net/world_flora/). Therefore, the **first strategic objective** for plant taxonomic research in South Africa is to produce an online Flora for the country by 2020. Families for which recent Floras or other treatises exist, or recent taxonomic revisions of plant genera are available, will relatively easily be incorporated into an electronic database that can be put online to serve this purpose, but groups that have not been treated, or treated only in part, will need to be prioritised in order to achieve GSPC Target 1.

Researching plant genera that are in need of revision, especially those of conservation or economic importance are examples of groups that should be treated as a priority. Gaps in taxonomic information at genus level can be identified and priorities determined accordingly. Therefore the **second strategic objective** is to revise priority plant genera for which existing treatments are inadequate.

The need to distinguish taxa that were Data Deficient (DD) according to the IUCN criteria for assessing conservation status (IUCN 2001) for taxonomic reasons from those that were DD for other reasons resulted in the use of the letter 'T' being adopted to flag those taxa (Victor 2006). Taxa listed as 'DDT' are regarded as priorities for taxonomic research efforts (Victor & Smith 2011), because conservation authorities should not expend limited financial resources on efforts to protect taxa that might be inseparable from common taxa. Meanwhile DDT species can cause significant fiscal implications for developers when the Environmental Impact Assessment (EIA) process is delayed by the occurrence of a potentially threatened species that is unclear because of taxonomic problems. If the taxonomic status is in doubt, this can lead to unnecessary wastage of financial resources, or potential neglect of a species in danger of going extinct; it can also impact on the ability to sustainably utilise a taxon of economic importance. The **third strategic objective** is to address this gap by resolving isolated taxonomic problems in species of conservation or economic importance.

A plant collecting programme for SANBI's herbaria will improve the value of collections and their associated data. Strategic prioritisation for expanding the collections through a systematic and efficient approach will expand the knowledge base of plant diversity. Collecting from specifically targeted geographical areas and focussing on plant taxa that are underrepresented in SANBI's herbaria would provide vital foundational information not only for taxonomic purposes, but also for providing information for end users, e.g. conservationists. The **fourth strategic objective** is therefore to improve the provision of foundational biodiversity information from herbaria and specimen label databases by prioritising collecting activities towards both geographical areas and plant taxa that are underrepresented in SANBI herbarium collections.

This is followed by recommendations to address concerns with data quality (see next section). Focussing on and inevitably addressing these recommendations will fulfil the objective of improving the quality of the data provided by herbarium collections as a resource for taxonomic and other research.

In summary, the strategic objectives for the *Strategy for plant taxonomic research in South Africa 2015–2020* are to:

1. Produce an open access, online checklist and Flora of South African plants by 2020.
2. Revise priority plant genera that are in need of revision.
3. Resolve taxonomic problems in single taxa or small taxon groups to improve the South African plant checklist.
4. Improve the herbarium collections as a research resource.

These strategic objectives are developed into three research programmes and a proposed plant collecting programme.

# Programmes of activity for taxonomic research

## *Research Programme 1: e-Flora*

Programme 1 addresses the first strategic objective, namely, to produce an open access, online Flora for South Africa (e-Flora) by 2020. This entails ensuring research capacity is available in prioritised plant families, and addressing gaps in taxonomic information that will contribute to the updating of the checklist of South African plants. The e-Flora will contribute to the World Flora Online, the first target of the GSPC, following the approach published by Victor et al. (2014).

The key tasks of Programme 1 are to:

1. Maintain or develop research capacity in priority families.
2. Produce treatises for geographical areas of South Africa that have not yet been completed.
3. Ensure that an accurate, updated checklist of South African plants is available online.
4. Produce an open access, online Flora for South African plants by 2020.

One way to prioritise which plant families should receive focused taxonomic research attention is to target those families with a high level of taxonomic problems. This analysis was conducted by Victor & Smith (2011), and the results showed that the families that should be prioritised for focussed taxonomic attention and in which capacity must be maintained or developed, are Aizoaceae (in a broad sense including Mesembryanthemaceae), Apocynaceae (in a broad sense including Asclepiadaceae and Periplocaceae), Asphodelaceae, Asteraceae, Campanulaceae, Ericaceae, Fabaceae (Leguminosae), Geraniaceae, Lobeliaceae, Oxalidaceae, Santalaceae, Scrophulariaceae and Thymelaeaceae. Capacity for research and curation of all of these families currently exists at SANBI and universities.

Family-scale treatments have often been done by production of a conspectus or Flora-style fascicle. Any family that has not been treated in the FSA series published by SANBI, or after 1960, is regarded as a priority. Treatments of large families (i.e. those containing more than 100 species) that are understudied (with more than 50% of taxa last revised prior to 1960), particularly those with taxa that present challenges to identify, are of particular importance and should be prioritised. These include the Cyperaceae, Hyacinthaceae, Malvaceae, Rhamnaceae and Rutaceae. Of the South African members of these families, the only one for which a family treatment is currently being

undertaken is the Cyperaceae. Active research is being conducted in Hyacinthaceae and Rutaceae. There is little capacity for the remaining families at research institutions, herbaria and universities. New staff members at SANBI will be required to develop expertise in these priority families.

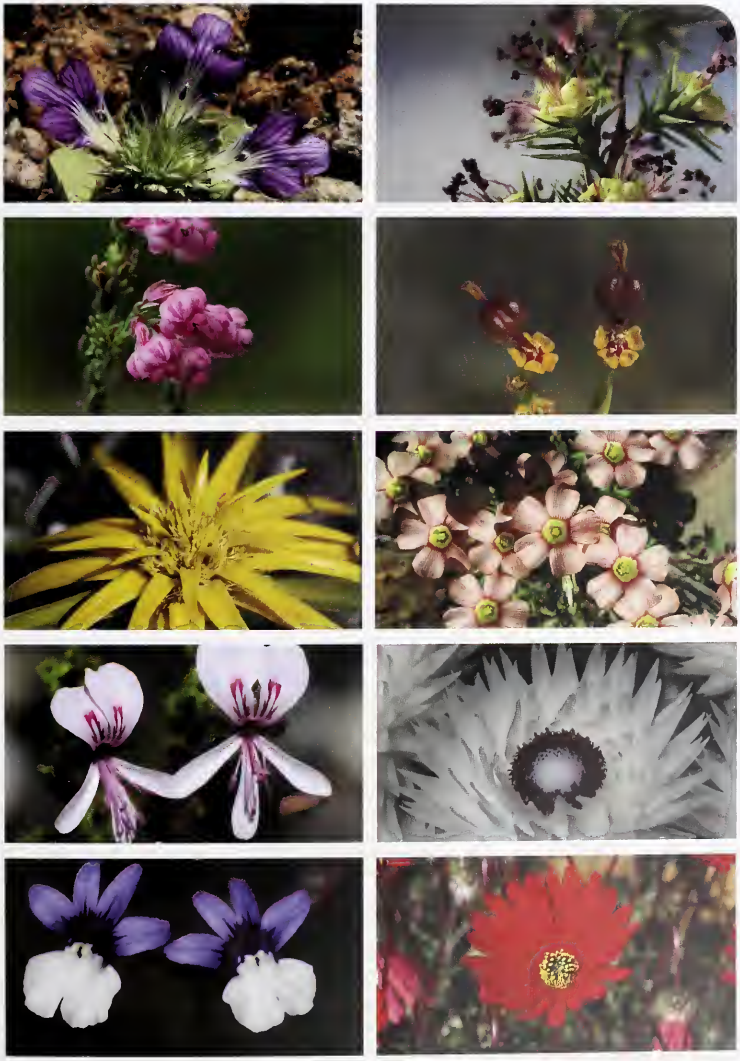
Of the cryptograms, one hornwort (Anthocerophyta), 13 moss (Bryophyta) and 31 liverwort (Marchantiophyta) families have not been covered in FSA or other family treatise publications. Because of the inadequate taxonomy of some groups and insufficient records and distribution data, especially in the central and western parts of southern Africa (Van Rooy & Van Wyk 2010), the remaining bryophyte families are regarded as priorities for research. Taxonomic research on these families is currently being undertaken by taxonomists at SANBI, in collaboration with scientists at universities and research institutions in the United States of America, Brazil, Finland and South Africa.

Victor et al. (2014) proposed that an online Flora of South African plants can be achieved using existing species descriptions. As such, SANBI has employed an e-Flora coordinator and an assistant who are dedicated to completing this task. The e-Flora coordinator is tasked with collaborating with taxonomists from around the country, including professionals and amateurs, to contribute to providing descriptions and information for the e-Flora. Descriptions will be obtained from the most recent revisions available, and those that are outstanding and unobtainable will be extracted from the regional Floras published by SANBI, which will have covered the flora of the entire country by 2020 (see under *Current state of taxonomic research*, p. 9).

A South African National Plant Checklist (currently known as the Plants of southern Africa, or POSA) has been created by SANBI and lodged on the SANBI website (http://posa.sanbi.org/searchspp.php). The checklist will be expanded and improved and should have links to descriptions and images for every taxon, as well as keys, which will constitute the e-Flora. SANBI has one dedicated scientist and an assistant to develop and maintain the checklist, to ensure that the e-Flora is completed by 2020.

## Research Programme 2: Revisions of plant genera

The strategic objective addressed by Programme 2 is to revise plant genera that are in need of revision, which will contribute to filling in gaps in knowledge of South Africa's flora. Research includes discovering (categorising and documenting) South Africa's flora. Analyses were conducted on angiosperms, gymnosperms and pteridophytes according to the methodology described in Victor et al. (2015). Sufficient data are lacking to do a similar analysis for bryophytes, however bryophyte priorities are addressed at family level in Programme 1.



Examples of priority genera in need of taxonomic revision.

To provide an objective list of genera requiring revision, indicators are used as criteria for prioritisation in the current analysis as described by Victor et al. (2014). The indicators used in this analysis were as follows:

## a. Date of the publication of the last revision

If the last treatment of a genus is that published in *Flora capensis* or up to the date when the final volume of *Flora capensis* was published (1933), it is of highest importance. Before the end of World War II, university-trained botanists were rare in South Africa (Rourke 1999), and use of advanced technology and multiple sources of data for revisions was minimal. Therefore genera covered by treatments published before 1945 are likely to be less comprehensive than those published thereafter. The 1970s coincided with the advent of electronic databases, as well as increased incorporation of more modern techniques in taxonomy following trends abroad. With few exceptions, any treatment published more recently than 1970 is considered to be not necessary to revise as the treatment should be modern and adequate. However, it should be noted that providing a revision can trigger opportunistic research and further refinement of the group, as clarifying the demarcation between taxa and provision of new keys can elucidate taxa that were not formerly apparent.

Taxonomic treatments in old revisions may well be adequate in terms of species concept and nomenclature, in which case it might not be necessary to revise the group. Conversely, some groups having been relatively recently revised may be inadequate or out of date. Quality of a revision is an important additional consideration, because even if a group has been revised very recently, if the rigor and scope of the work is not up to standard, it would necessitate further work. If this becomes apparent to specialists then the group can be included on the priority list for revision if motivation is provided. Thus although the date of last revision was used as an indication of whether a new revision is required, the list was further refined by circulating it to specialists and considering expert advice.

## b. Proportion of unidentified specimens of genera in SANBI herbaria

A high proportion of unidentified herbarium specimens within a genus can be an indicator of potential taxonomic problems resulting from inadequate revisions. A revision (whether old or new) may be inadequate due to any of the following factors: a lack of clear descriptions of species, lack of clarity of generic delimitations, keys that are difficult to use and/or the presence of undescribed species. The number of unidentified specimens in the PRECIS database was used to detect potential problematic genera that require prioritising for taxonomic research, and this forms another criterion for selecting priority genera.

*Aloe ferox*, an economically important plant species. Photographer: Geoff Nichols.

## c. Proportion of taxa classified as DDT

Species that are classified as DDT on the South African Red List are lacking in information often as a result of inadequate or incomplete information provided in taxonomic literature (especially distribution information). The proportion of species listed as DDT in each genus therefore provides a useful indication of potential need for revision of a genus, and was used to determine priority groups for taxonomic research.

## d. Economic importance

The fourth criterion used to determine priority genera for revision was economic importance of the plant group. The top seven economically important families were determined by conducting a survey of the literature as well as expert advice. Economically important plant families are considered to be those that have a higher proportion of taxa of importance in South Africa with respect to their status such as crop plants, food plants, medicinal value, horticultural value, timber, or invasive or naturalised alien species. A literature survey and opinion survey amongst South African taxonomists revealed that the top seven economically important plant families in South Africa are Poaceae (frequently acknowledged as the most economically important plant family in the world), Fabaceae (considered to be the most important dicotyledonous plant family in the world according to Harborne [1994]), Geraniaceae, Rutaceae, Apiaceae, Asphodelaceae and Asteraceae.

## e. Proportion of infrageneric taxa occurring in South Africa

The final criterion used to prioritise genera for taxonomic revision was the proportion of taxa in each genus occurring in South Africa. When the majority of the genus does not occur in South Africa, the cost of doing a revision escalates when fieldwork is necessary to collect material for examination, or to conduct field-based natural history observations. For example *Buchnera* and *Bassia* were both excluded from priority lists because more than 75% of the species do not occur in South Africa. It is preferable to do a comprehensive study, such as a monograph, of a complete group, rather than a partial investigation, therefore for the next five years the priority will be to strategically focus on genera that are endemic or near-endemic to South Africa.

From these analyses, a list of plant genera categorised according to their priority for revision (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies) was developed and circulated widely amongst taxonomists in South Africa and abroad. Because these objective analyses could inadvertently ignore important plant genera that did not qualify using the indicators, specialists were asked to contribute suggestions for genera to be prioritised for revision based on their expert knowledge, giving a sound justification

as to why the genus should be considered. Additional justifications for inclusion of a genus as a priority for revision included:

- Whether or not the revision is satisfactory in terms of including an effective key for plant identifications, clear descriptions that adequately delimit taxon boundaries, and sufficient clarity on taxonomic status of each taxon.
- Whether or not a large number of undescribed taxa that cannot be adequately placed within the genus without revising the whole genus are known to exist.

The preliminary results of the analyses were thus used in conjunction with expert input to develop the list of priority genera.

*Tulbaghia* cf. *pretoriensis*, a taxon that is not well distinguished from *T. acutiloba* and is therefore classified as DDT on the Red List of South African plants. Photographer: Janine Victor.

## Research Programme 3: Data Deficient plants

The aim of this programme is to solve problems targeting single species or small groups of related taxa of conservation or economic importance in large genera that are otherwise not in need of revision. Taxonomic problems impede the determination of conservation status of threatened taxa, or the potential sustainable use of economically important taxa. These taxa can therefore escape conservation attention.

The process of assessing the Red List status of plant species is often hindered because of uncertainties in taxonomic status of the taxon. For over 1 000 of the plant taxa that are possibly threatened with extinction, taxonomic problems exist and therefore insufficient data are available to accurately assess their conservation status. At the time of writing of this report (June 2015), there are 246 taxonomically problematic taxa that are not covered by revisions (http://www.sanbi.org/biodiversity-science/foundations-biodiversity/biosystematics-collections/biosystematics-strategies). These taxa constitute the priority list of this programme. Additional taxa of economic importance that are taxonomically problematic were listed in cases where the genus as a whole does not require revision. Projects dealing with a single species and its nearest relatives have the advantage of being of a manageable size suitable for students enrolled in Honours courses. The programme will be promoted at universities to stimulate interest in, and the involvement of, students in small taxonomic research projects that could result in publications, intellectual growth, and by implication, in capacity of taxonomy.

Allowance is made for the possibility that resolving taxonomically problematic species listed under this programme may necessitate revising the genus to which it belongs.

## Cross-cutting considerations for research

Conducting taxonomic research in such a way that insight is provided into other fields, especially focusing on determining evolutionary relationships and specialisations, remains of paramount importance. Studies on function/process (as opposed to structure/pattern) will both inform taxonomic work and provide high-profile research outputs for attracting funding. For example, Desmet et al. (2002) recommend that in addition to describing infraspecific variation, taxonomists should formulate hypotheses as to how this variation is distributed in the landscape, and how it came about, so that spatial components of evolutionary processes can be identified for purposes of conservation of evolutionary processes. Another example is determining phylogenetic diversity, a conservation tool that measures quantitatively the genealogical history of a group of species, which is then used to prioritise species for conservation (Hartmann & André 2013).

# Programme of activity to improve the herbarium collections as a research resource

## *Plant Collecting Programme*

This programme gives a generalised outline of proposed actions to improve the coverage of the country and the flora by herbarium collections. It is recommended that herbarium curators of all institutions develop more detailed plans to prioritise gaps in their own collections that are relevant to the activities, areas and taxa covered by their herbaria.

Plant collecting in the Tanqua Karoo.

The following priorities are identified for targeted collecting trips to improve the taxonomic and geographic representation of plant specimens in herbaria:

## a. Taxa that are underrepresented in the herbarium collection

The ideal number of plant specimens representing each taxon will differ between herbaria, and between taxa. As a general guideline for SANBI herbaria, if fewer than five specimens exist for one taxon, it is then considered to be underrepresented and should be prioritised for collecting. Targeting underrepresented species should ideally be conducted by taxonomists who specialise in the family of which the taxon is a member, and with experience in the field, to prevent unnecessary wastage of resources. The list of undercollected taxa should be used in conjunction with the list of plant taxa classified as DDT in the Red List and genera prioritised for taxonomic research in Programme 2, because most taxa prioritised as DDT are also undercollected or are members of genera requiring taxonomic revision.

## b. Geographically underrepresented areas

The SANBI herbaria house collections from throughout South Africa, although this particularly applies to the National Herbarium. Therefore the BRAHMS database can be interrogated to derive areas which are underrepresented in terms of herbarium specimens. In the case of SANBI herbaria, any quarter degree grid that has fewer than 50 specimens in herbaria is considered to be underrepresented. Because of the large areas that are undercollected, it is recommended that all quarter degree grid squares with fewer than 10 specimens (especially those with none) are targeted as first priority. Once there is more complete coverage of these areas, the next priority will be to target areas with fewer than 50 specimens per quarter degree grid square.

Because this is a vast area of the country, further strategic identification of important areas to target for expanding herbarium specimen holdings are necessary. It is recommended that collecting plans are developed on an annual basis to target for example areas earmarked for development within underrepresented areas, and areas that have high diversity but are underrepresented due to being in remote and inaccessible locations. Areas known to have low diversity should arguably be excluded from a targeted collecting programme, but care should be taken not to omit pockets of high diversity in landscapes that are otherwise reasonably homogeneous.

As an incentive to improving collections and to reduce costs of this programme, herbaria, especially those of SANBI, should offer a free identification service to plant collectors who specifically target undercollected areas or undercollected taxa prioritised for collection, in return for donation of high quality specimens that adhere to quality standards (i.e. fertile specimens fully representative of the plant, along with good field notes).

Maps of undercollected areas should be generated annually to monitor and illustrate progress with improving representation of specimen coverage. As there are over 100 quarter degree grid references with fewer than 10 specimens in SANBI herbaria, an initial aim could be to reduce this by five quarter degree grids every year (targeting areas earmarked for development). Progress with collection of underrepresented plant taxa can similarly be monitored by generating lists of taxa with five or fewer specimens annually and tracking progress, and should be available on the website.

Collection of samples for comparative DNA studies, including barcoding, is encouraged as a routine part of fieldwork for taxonomic research. It is vital that such samples are linked to correctly identified voucher specimens. Although it is not currently prioritised as an independent exercise in the Strategy, once a sufficiently comprehensive library of DNA samples/barcodes has been accumulated on the flora of South Africa, molecular techniques will be able to play an important role in the identification and classification of specimens. This is likely to become an increasingly more important activity in future updates of the Strategy once revisions of the most taxonomically problematic groups have been achieved.

## Recommendations for ensuring data quality

It is critical that the quality of data derived from herbarium specimen labels and disseminated to end users is accurate. Data validation and detailed checking is a key activity undertaken by all taxonomists and support staff at SANBI rather than a separate programme. All herbaria that capture, house, maintain and disseminate electronic data of herbarium label information should adhere to the following recommendations:

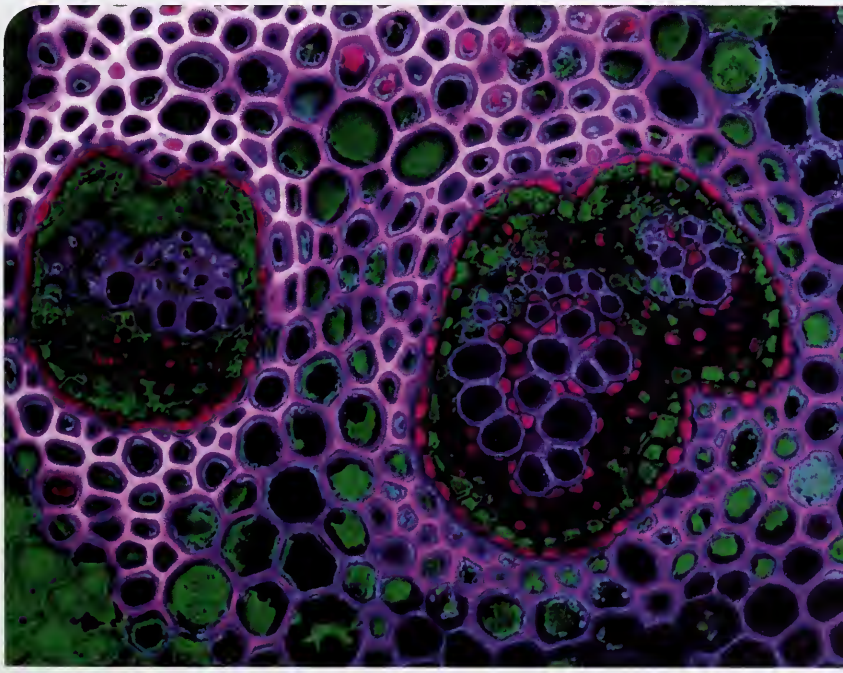
- Quality standards for populating plant specimen databases need to be set to minimise errors, and persons responsible for populating the database must take care in transcribing information and adhere to quality standards, ensuring that the label information is accurately mirrored in the database.
- Two main sources of errors exist in most databases that hold plant specimen label information. Data need to be screened for errors in: (1) names (identification) and (2) localities (georeferenced as well as lower resolution such as quarter degree grid) on a regular basis. This can be done by, for example, generating taxon distribution maps and identifying points that appear to be out of place.
- Errors should be corrected by scientists or technical support officers who are experienced at identifying the taxa concerned, and have knowledge of the geography of the area concerned. Identifications and locality, georeferenced and quarter degree grids must all be corrected on databases to ensure that the data accurately mirrors data given on the specimens.
- Georeferencing of specimen locality information should be done by experienced people.
- When herbaria send specimens to other institutions on loan, it should be

made a requirement that following completion of the study, the loan recipient should assist in updating the corresponding information in the database, or be available to assist the responsible staff member in updating the database to accurately reflect the latest information.

Within the three SANBI herbaria, all scientists and support staff are tasked with data cleaning, and quality control of new information added to the database is in place. Monitoring of progress is an essential component of improving data quality in SANBI herbaria as they are providing a service to the public. In the BRAHMS database it is possible to develop a tool to show progress with verification and changes resulting in improvement of quality over time. Changes and updates that have been made to the database should be summarised and displayed on a SANBI website page at quarterly intervals to illustrate to end users how progress is being made to clean up data.

# Discussion and conclusions

An analysis of gaps in taxonomic knowledge has enabled the establishment of four strategic objectives, as well as three research programmes and a collecting programme that will address the strategic objectives. Within SANBI, existing capacity in taxonomic research will be utilised towards addressing the priorities of the Strategy. The Strategy will be further promoted amongst university researchers to stimulate their involvement, and in particular to stimulate interest of potential taxonomists in projects from, especially, Programme 3. Such projects have the additional advantage of being cross-cutting between taxonomy, population biology, ecology and conservation, and are therefore ideal for students who have not yet specialised in a particular field of research.



Transverse section of a fern midrib (20×). Photographer: Daphne Zbaeren-Colbourn; source: http://www.nikonsmallworld.com/galleries/entry/2008-photomicrography-competition/33.

A primary objective of taxonomy is to develop a natural and predictive classification system with high information content and that reflects evolutionary relationships among plants. To achieve this, results from molecular studies are integrated with other sources such as morphological, anatomical, cytological, physiological and palynological studies. Modern revisions also include a phylogeny to circumscribe the group of interest, identify nearest relatives, and identify patterns of character evolution. Understanding evolutionary relationships can assist in understanding more complex characteristics of an organism, such as the causal factors for its rarity as an example, leading to enhanced ability for priority setting by conservationists and development of management plans. The value of taxonomic information produced should be enhanced by research methodologies and dissemination channels that add value to the products of the research.

Enhancing the availability of taxonomic information to the public through popular publications is one of the most important requirements of end users. There is a great demand for popular publications such as field guides with images to aid identification. In order to achieve dissemination to the broader public and other stakeholders, and thus for taxonomic research to have a positive impact on society, it would be of great benefit to develop online identification tools (including apps for mobile devices) and information portals in line with the first strategic objective of this Strategy. Electronic keys of the largest genera and families, with images of species and key characters, would be particularly useful to end users. An area for development of disseminating taxonomic information to the public is in applications for mobile cellular phones and tablets. An example that could be followed is the free iPhone app, Plant-O-Matic (see: http://go.nature.com/9pg7vQ), which gives access to the records of all plants in the Americas, over 88 000 species, with links to images of herbarium specimens from the Missouri Botanical Garden's Tropicos database (Nature Plants Editorial 2015).

The SANBI website hosts a list of taxonomic priorities for research and expertise of botanists, both professional and amateur, from herbaria and universities countrywide, as well as priority genera for research. This list will be updated regularly and act as a resource to stimulate interest in the Strategy, in this way coordinating taxonomic research on the South African flora.

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*Pterocelastrus*, a priority genus for taxonomic research. Photographer: Geoff Nichols.

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